

*IRT–STIMULUS CONTINGENCIES IN CHAINED SCHEDULES: IMPLICATIONS FOR THE CONCEPT OF CONDITIONED REINFORCEMENT*RAFAEL BEJARANO¹ AND TIMOTHY D. HACKENBERG²HENDERSON STATE UNIVERSITY,¹ AND
UNIVERSITY OF FLORIDA²

Two experiments with pigeons investigated the effects of contingencies between interresponse times (IRTs) and the transitions between the components of 2- and 4-component chained schedules (Experiments 1 and 2, respectively). The probability of component transitions varied directly with the most recent (Lag 0) IRT in some experimental conditions and with the 4th (Lag 4) IRT preceding the most recent one in others. Mean component durations were constant across conditions, so the reinforcing effect of stimulus change was dissociated from that of delay to food. IRTs were longer in the Lag-0 than in the Lag-4 conditions of both experiments, thus demonstrating that stimulus change functioned as a reinforcer. In the Lag-0 conditions of Experiment 2, the Component-1 IRTs increased more than the Component-2 IRTs, which in turn increased more than the Component-3 IRTs. This finding runs counter to the conditioned-positive-reinforcement account of chained-schedule responding, which holds that the reinforcing effect of stimulus change should vary in strength as an inverse function of the delay to the unconditioned reinforcer at the end of the chain because conditioned reinforcement is due to first- or higher-order classical conditioning. Therefore, we present other possible explanations for this effect.

Key words: chained schedules, conditioned reinforcement, interresponse times, key pecks, pigeons

Chained schedules of reinforcement have long been of theoretical interest, in part because they seem to model temporally extended behavior patterns, such as those involved in preparing a meal or in making a telephone call. On such schedules, presentations of an unconditioned reinforcer are contingent on completing a series of schedule requirements, each of which is correlated with a different exteroceptive stimulus (Ferster & Skinner, 1957, chap. 12). On a chained variable-interval (VI) 60-s VI 60-s schedule, for example, responses in the presence of the terminal-component stimulus produce an unconditioned reinforcer (e.g., food) every 60 s on average, and responses in the presence of

the initial-component stimulus produce the terminal-component stimulus, again, every 60 s on average.

Two major accounts of chained-schedule responding have been proposed. The older of these holds that responding in the early components is due to the reinforcing effect of the stimuli correlated with the later components (i.e., to conditioned positive reinforcement), which in turn is due to the backward transfer of reinforcing efficacy from the unconditioned reinforcer via first- or higher-order classical conditioning (Kelleher & Gollub, 1962). This explanation has been challenged by a more recent account, which holds that chained-schedule responding is determined by its delay to the unconditioned reinforcer, and not by the reinforcing effect of stimulus change (Baum, 1973; Staddon, 1983).

One reason why the conditioned-positive-reinforcement explanation has been called into question may be that the reinforcing effect of stimulus change has been difficult to dissociate from the effect of the delays to the unconditioned reinforcer. Consider, for example, comparisons between chained and tandem schedules, which differ from chained only in that the same stimulus is correlated with all of the components (Ferster & Skinner, 1957, chap. 8). That is, programmed stimulus

This research was supported in part by NSF Grant SES 9982452 and was part of a doctoral dissertation submitted by the first author to the Graduate School at the University of Florida. We thank Marc Branch, Keith Berg, Cecil Mercer, and Timothy Vollmer for their suggestions and helpful comments on an earlier version of this manuscript, and the University of Kansas Schiefelbusch Institute for Life Span Studies at Parsons for assistance with its preparation.

Correspondence concerning this article should be addressed to Rafael Bejarano at Henderson State University, 1100 Henderson St., P.O. Box 790, Arkadelphia, AR 71999 (e-mail: bejarar@hsu.edu), or to Timothy D. Hackenberg, Department of Psychology, University of Florida, Gainesville, FL 32611 (e-mail: hack1@ufl.edu)
doi: 10.1901/jeab.2007.88-215

changes do not accompany the transitions between the components of tandem schedules. So, if stimulus change has a reinforcing effect, response rates should be higher in the early components of the chained schedules than in corresponding tandem schedules. In actuality, however, response rates typically have been lower in the early components of the chains (Jwaideh, 1973; Kelleher & Fry, 1962; Thomas, 1964, 1967; Wallace, Osborne, & Fantino, 1982). At first glance, this finding seems to show that stimuli in chained schedules do not function as reinforcers. Another possibility, however, is that response rates in the early components of the chains were low because the stimuli correlated with these components signaled long delays to the unconditioned reinforcer, thus canceling out the reinforcing effect of the stimuli correlated with the later components.

A similar interpretive problem is associated with comparisons between chained schedules and multiple schedules that arrange response-independent transitions between extinction and reinforcement components. The rationale for such comparisons is that, if the contingency between responding and stimulus change determines responding in the early components of chained schedules, response rates should be higher in the early components of these schedules than in the corresponding (extinction) components of the multiple schedules. Consistent with this prediction, response rates have tended to be higher in the early components of the chains than in the extinction components of the multiple schedules (Catania, Yohalem, & Silverman, 1980; Ferster & Skinner, 1957). Nevertheless, this finding cannot be attributed unreservedly to the contingency between responding and stimulus change because the unconditioned reinforcer would have been postponed by low response rates in the early components of the chained schedules, but not by low response rates in the extinction components of the multiple schedules. In other words, responding in the early components of the chains may have been determined primarily by the contingency between response rate and the delays to the unconditioned reinforcer, and not by the contingency between responding and stimulus change.

More recent studies by Williams and his colleagues have yielded findings that are

clearly consistent with the conditioned-reinforcement account of chained-schedule responding (Royalty, Williams, & Fantino, 1987; Williams & Royalty, 1990). Royalty et al., for example, tested the prediction that, if stimulus change functions as a conditioned reinforcer, then delaying component transitions should decrease response rates in the early components of chained schedules, just as delaying food reinforcement has been shown to do on simple schedules (for reviews of the literature on delayed reinforcement, see Renner, 1964; Schneider, 1990). To test this prediction, Royalty et al. reinforced pigeons' key pecks on a chained VI 33-s VI 33-s VI 33-s schedule. Across experimental conditions, they imposed an unsignaled 3-s delay between (a) initial-component responses and the transitions to the middle component, (b) middle-component responses and the transitions to the terminal component, or (c) terminal-component responses and food. To keep the mean interfood interval (IFI) constant across conditions (and thereby minimize the effect of the delays to the unconditioned reinforcer), Royalty et al. also decreased the duration of the component in which this delay was arranged to 30 s (e.g., when the transitions to the middle component were delayed, the duration of the initial component was decreased). Consistent with the conditioned-reinforcement account of chained-schedule responding, delaying the stimulus changes decreased response rates in the component in which they occurred, without affecting either the response rates in the other two components or the delays to food.

The aim of the two experiments reported herein was to investigate the predictive utility of the conditioned-positive-reinforcement and reinforcement-delay accounts of chained-schedule responding in situations involving contingencies between interresponse times (IRTs) and component transitions. Specifically, if stimulus change has a reinforcing effect, then a higher probability of stimulus change after long than after short IRTs should increase IRT length in the early components, even if the delays to the unconditioned reinforcer are held constant across experimental conditions. If delay to the unconditioned reinforcer is the primary determinant of chained-schedule responding, however, then a higher probability of component transitions

after long than after short IRTs should have no effect on IRT length, assuming the delays to the unconditioned reinforcer do not vary systematically with IRT duration.

To test these predictions, we varied the probability of transitions to the later components of chained schedules (and their accompanying stimulus changes) directly with IRT length in the early components of two- and four-component chains (Experiments 1 and 2, respectively). We used procedures known technically as stochastic reinforcement of waiting (Weiss, 1970) or linear-IRT (Galbicka & Platt, 1984) schedules on which the probability of a component transition after each IRT is given by the equation:

$$p = t/T \quad (1)$$

where p is the probability of component transitions, t is the length of each IRT, and T is the programmed mean component duration.

Note that, as long as t is not greater than T , the obtained mean component durations will not vary systematically with IRT length, so the mean IFI (i.e., the mean delays to food) should remain constant. On the two-component chain used in Experiment 1, for example, the programmed duration of each component was 30 s. So, the probability of transitions to the terminal component was 0.1 given a 3-s IRT, 0.2 given a 6-s IRT, 0.5 given a 15-s IRT, and so on, whereas the programmed mean IFI was 60 s.

We used two variants of linear-IRT schedules to arrange the component transitions, one in which the most recent (Lag 0) IRT was divided by the programmed mean component duration and another in which the fourth (Lag 4) IRT preceding the most recent one was divided by this value. Platt (1979) had shown that IRTs are longer when food reinforcement is contingent on the Lag-0 IRT than when it is contingent on the Lag-4 IRT, presumably because the delay to reinforcement is shorter in the former case. Based on this assumption, we likewise expected longer IRTs in the Lag-0 than in the Lag-4 condition.

To summarize, the two experiments reported herein were based on the rationale that if stimulus change has a reinforcing effect on chained-schedule responding, then IRTs in the early components of chained schedules might be expected to vary directly with the

probability of the stimulus changes that occur during transitions to the later components. To investigate this possibility, we used linear-IRT schedules to arrange component transitions in two-component (Experiment 1) and four-component (Experiment 2) chains. Because such schedules differentially reinforce long IRTs while holding component durations constant, any changes in IRT length that might occur across conditions would not be attributable to the delays to food signaled by the different stimuli in the chain or to the contingency between response rate in the early components and the time to food. Consequently, such changes would have to be explained in terms of the reinforcing effect of stimulus change.

EXPERIMENT 1

METHOD

Subjects

Four white Carneau pigeons (*Columba livia*)—numbered 68, 790, 2167, and 8269—served as subjects. None had served in other experiments, but all had been exposed to several schedules of reinforcement in undergraduate laboratory courses on operant behavior. The pigeons were maintained at approximately 80% of their free-feeding body weights by means of postsession feeding and were individually housed in a colony room where they had continuous access to water and grit. The room was illuminated on a 16.5:7.5 hr light/dark schedule.

Apparatus

The experiment was carried out in a standard operant chamber for pigeons that was 31.1 cm long, 34.9 cm wide, and 34.9 cm high. The chamber was enclosed in a sound-attenuating shell. Three response keys (2.54 cm in diameter) were located on the experimental panel 23.2 cm above the grid floor. The left and right keys were 5.8 cm and 5.5 cm from the left and right walls, respectively, whereas the center key was located 5.8 cm from both side keys. A force of approximately 0.35 N was required to operate all three keys, of which only the left-most one was used in the experiment.

A houselight located 5 cm above the middle response key provided diffuse illumination, and a ventilation fan and a white noise

generator helped mask extraneous sound. A centrally located aperture, measuring 4.5 by 5.2 cm and positioned 6.7 cm above the grid floor, was located in the experimental panel and provided access to mixed grain. An IBM-compatible microcomputer (using Med-PC® software) scheduled the presentation of stimuli and recorded the occurrence of key pecks at a sampling rate of 200 times per s. The computer and the experimental chamber were located in different rooms.

Procedure

A two-component chained schedule was used. In the initial component, the left key was lit red, and transitions to the terminal component occurred on a linear-IRT schedule (see below). In the terminal component, the left key was lit white, and responses produced food on a random-interval (RI) 30-s schedule; that is, food was presented if a probability gate that was interrogated every 0.3 s yielded values of less than or equal to 0.01. Food presentations consisted of 3-s access to a food hopper, during which times the feeder light was illuminated and all other lights were dark. After the 3 s of food access, the food hopper was withdrawn, and the initial-component schedule was reinstated, thereby beginning a new cycle. Thirty such cycles comprised the experimental sessions, which were conducted 7 days a week.

The experiment consisted of two conditions. In both conditions, food reinforcement was presented in the terminal component on the aforementioned RI 30-s schedule, and component transitions occurred on a linear-IRT schedule (see Equation 1). Specifically, the probability of component transitions was calculated after every initial-component response by first dividing either the Lag-4 or the Lag-0 IRT by 30 (depending on the condition in effect) and then interrogating a probability gate. If the probability gate returned a value less than or equal to the quotient, the terminal-component stimulus was presented. To minimize the between-subject variability, all subjects were exposed to the experimental conditions in the order Lag 4, Lag 0, Lag 4, Lag 0. Thus, every subject received two exposures to each condition.

Table 1 shows the total number of sessions in each condition for each subject. Each condition remained in effect for a minimum

Table 1

Number of sessions in each condition of Experiment 1 for each subject.

Subject	Condition			
	Lag 4	Lag 0	Lag 4	Lag 0
68	15	15	15	32
790	25	33	28	30
2167	15	15	16	28
8269	21	17	15	17

of 15 sessions and for as many additional sessions as were required for responding to meet the stability criteria. Specifically, no upward or downward trend could be apparent in the mean initial-component IRTs from the most recent five sessions (the stability of the terminal-component IRTs was not considered because they seemed irrelevant to whether or not stimulus change is reinforcing). In addition, the amount of variability over the most recent 10 sessions had to be minimal, as determined in the following manner: First, two grand means were calculated—one based on the mean initial-component IRT from each of the most recent five sessions and another based on the mean initial-component IRT from each of the preceding five sessions. Then the difference between these grand means was calculated. If this difference was less than .10, the subject was advanced to the next condition, or in the final condition, the experiment was terminated.

Throughout the experiment, the latencies to the first response in the initial component of each cycle and the first five IRTs of each session were excluded from the calculations of the probability of component transitions. The latencies were excluded from such calculations because they are not in the same nominal class of temporal events as IRTs. That is, whereas IRTs were measured from the occurrence of one key peck to the occurrence of the next one, latencies were measured from the onset of the initial-component stimulus to the first key peck to occur in its presence. The first five IRTs of each session were excluded from such calculations because, in the Lag-4 condition, the probability of transitions to the terminal component depended on the fourth IRT in advance of the most recent one, so the first calculation of this probability in each session could not be made until a minimum of five IRTs (or six responses) had occurred. To keep

this procedural feature constant throughout the experiment, the first five IRTs of each session were also excluded from calculations of the probability of component transitions in the Lag-0 condition.

RESULTS AND DISCUSSION

Figure 1 shows the mean IRTs for each subject. The left panels show means of the mean initial-component IRTs from each of the last five sessions of each of the four conditions, as well as the ranges of values that composed these grand means. The right panels show the corresponding means and ranges from the terminal component. As can be seen, the terminal-component IRTs did not vary systematically across conditions, whereas the initial-component IRTs increased by 20% or more in all eight exposures to the Lag-0 condition (i.e., 4 subjects \times 2 exposures). For all 4 subjects, IRT length increased more in the first than in the second exposure to the Lag-0 condition, with the largest and smallest of these increases occurring in Pigeons 2167 and 8269, respectively.

Figure 2 shows relative frequency distributions of initial-component IRTs for a representative subject (Subject 68), constructed from the IRTs in the last five sessions of the first presentation of the Lag-4 and Lag-0 conditions. The modal (0–0.2) IRT bin was lower in the Lag-0 (open circles) than in the Lag-4 (closed squares) condition. In other words, IRTs were distributed over a wider range in the Lag-0 condition, which explains the increases in the mean IRT that were depicted in Figure 1 (specifically, the first Lag-0 condition in the left panel).

Figure 3 shows mean component durations for each subject. The left panels show means of the mean initial-component durations from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. The right panels show the corresponding means and ranges from the terminal component. With the exception of Pigeon 790 (whose mean terminal-component durations were slightly longer in the Lag-0 than in the Lag-4 condition), mean component durations did not vary systematically across conditions. However, the mean durations of the initial component were somewhat longer than those of the terminal component (see, e.g., Subjects 790 and 2167).

In sum, this experiment showed that a contingency between Lag-0 IRTs and stimulus change can increase IRT length in the initial component of a two-component chain. These results cannot be attributed to the delays to food signaled by the initial-component stimulus nor can they be ascribed to a contingency between IRT length in the initial component and the time to food, because the mean IFI was kept from varying systematically across conditions. Consequently, these findings may be attributed to the reinforcing effect of stimulus change, consistent with the aforementioned account of chained-schedule responding in terms of conditioned positive reinforcement.

EXPERIMENT 2

A question raised by the results of Experiment 1 was whether stimulus change also can increase IRTs in the early components of extended chains (i.e., chains consisting of more than two components). The aforementioned study by Royalty et al. (1987) showed that the middle-component stimulus in a three-component chain can function as a reinforcer, but the possibility remained that the reinforcing effect of stimulus change does not extend to the early components of longer chains. To investigate this possibility, we conducted a second experiment in which component transitions in a four-component chain occurred on linear-IRT schedules like those used in Experiment 1.

As in that experiment, component transitions were contingent on Lag-0 IRTs in some conditions and on Lag-4 IRTs in others. Our reasoning was similar to that in Experiment 1. That is, if the stimuli in a four-component chain have a reinforcing effect, then the IRTs in the early components should be longer under a Lag-0 than under a Lag-4 contingency. Otherwise, IRTs in these components should not vary with IRT lag.

METHOD

Subjects and Apparatus

The subjects and apparatus were those used in Experiment 1.

Procedure

A four-component chained schedule was used. Components 1–4 were correlated with

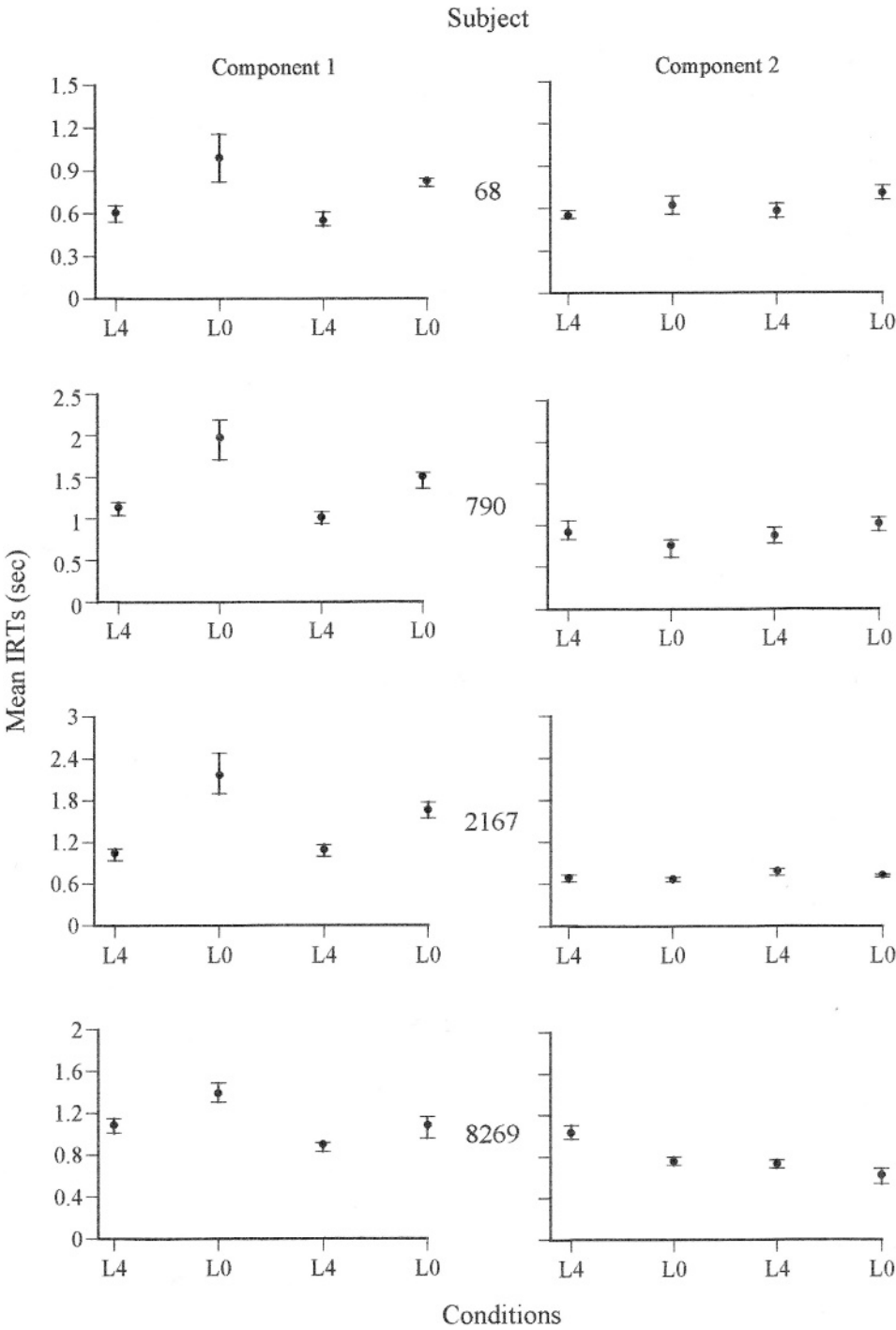


Fig. 1. Mean IRTs during the Lag-4 and Lag-0 conditions of Experiment 1. The first, second, third, and fourth rows of panels show data for Pigeons 68, 790, 2167, and 8269 in that order. Left panels show means of the mean Component-1 IRTs from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. Right panels show the corresponding means and ranges from Component 2. The Lag-4 and Lag-0 conditions are labeled "L4" and "L0," respectively.

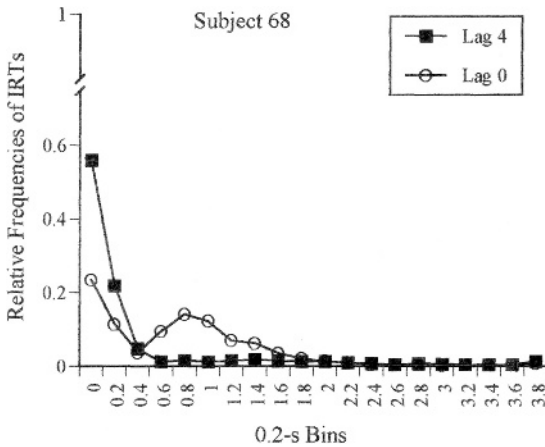


Fig. 2. Relative frequency distributions of IRTs (in 0.2-s bins) for a representative subject, Pigeon 68, constructed from the last five sessions of this subject's initial exposure to the Lag-0 (open circles) and Lag-4 (closed squares) conditions. The numbers on the x-axis represent the lower limit of each bin (e.g., 0.3-s IRTs are in the 0.2-s bin). The right-most bin contains IRTs greater than or equal to 3.8 s.

blue, green, red, and white key lights, respectively. The food-access times, the number of cycles per daily session, and the number of sessions per week were the same as in Experiment 1. Likewise, for the reasons given in the Methods section of that experiment, the first five IRTs in each component in each session, and all latencies to the first response in each component, were excluded from calculations of the probability of component transitions. The component transitions and the presentation of food in the terminal component occurred on linear-IRT schedules, with programmed mean component durations of 15 s. Unlike Experiment 1, food was delivered on a linear-IRT schedule in order to simplify the programming of the contingencies.

Experiment 2 consisted of four conditions to which each subject was exposed twice in a partially counterbalanced order (see Table 2 for each subject's order of exposure to the conditions and for the total number of sessions in each). In some conditions, a Lag-4 contingency operated in all four components. In other conditions, a Lag-0 contingency operated in one of the first three components, and the Lag-4 contingency operated in all of the others. When transitions to the second component were contingent on Lag-0 IRTs, for example, food deliveries and transitions to Components 3 and 4 were contingent on Lag-4 IRTs.

Each condition remained in effect for a minimum of 15 sessions, and for as many additional sessions as were required for responding to meet the stability criteria. As in Experiment 1, responding was considered stable in a given component when the mean IRTs in each of the most recent five sessions exhibited no upward or downward trend and the mean of those means differed by no more than .10 from the grand mean of the mean IRTs in the preceding five sessions. For example, when the mean Component-1 IRTs from the most recent five sessions exhibited no upward or downward trend, and the mean of those means differed by no more than .10 from the mean of the mean Component-1 IRTs from the preceding five sessions, responding in Component 1 was deemed stable. If the Lag-4 contingency was in effect in all four components, responding had to be stable only in the component in which the Lag-0 contingency would be in effect during the following condition. If the Lag-0 contingency was already in effect in one of the components (e.g., Component 2), responding had to be stable both in that component and in the component in which the Lag-0 contingency would be in effect during the following condition (e.g., Component 3). Finally, if the next condition involved a return to the Lag-4 contingency in every component, or the experiment was in the final condition, responding only had to be stable in the component in which the Lag-0 contingency was currently in effect.

RESULTS AND DISCUSSION

Figure 4 shows mean IRTs in Components 1–4 for each subject in each condition. Subject numbers appear in the graphs for Component 1. The first column of panels shows means of the mean Component-1 IRTs from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. The second, third, and fourth columns show the corresponding means and ranges from Components 2, 3, and 4, respectively. It should be noted that the labels for each condition indicate the contingency (Lag-4 or Lag-0) that was in effect during the specific component.

As can be seen, the mean Component-4 IRTs did not vary systematically across conditions, whereas the mean IRTs in Components

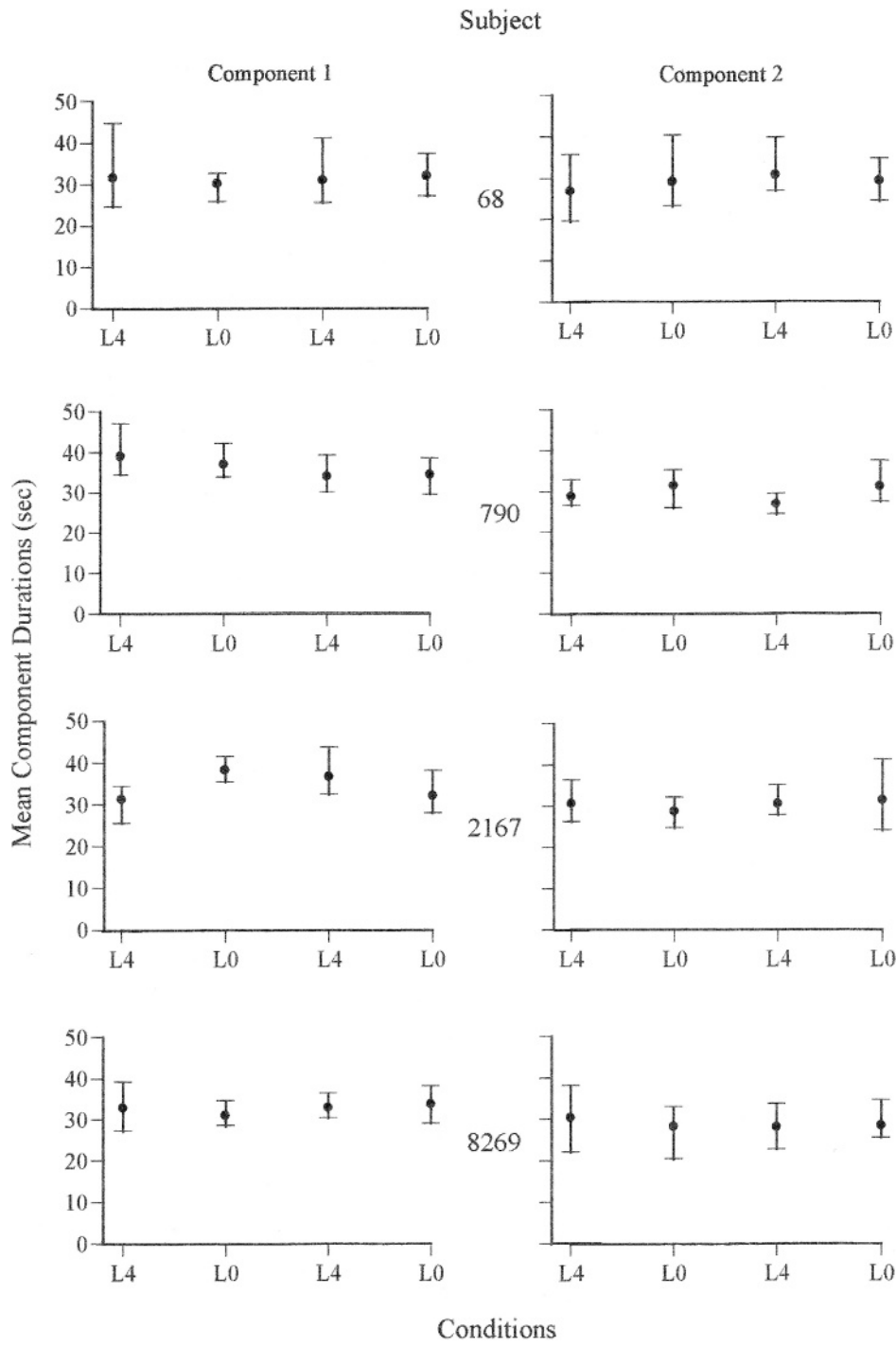


Fig. 3. Mean obtained component durations in each condition of Experiment 1. The first, second, third, and fourth rows of panels show data for Pigeons 68, 790, 2167, and 8269 in that order. Left panels show means of the mean Component-1 durations from each of the last five sessions of each condition, as well as the range of values that composed these grand means. Right panels show the corresponding means and ranges from Component 2. Lag-4 and Lag-0 conditions are labeled "L4" and "L0," respectively.

Table 2

Order of exposure to the conditions of Experiment 2 for each subject and number of sessions (in parentheses) in each condition.

Subject		Conditions						
68	N(23)	3(19)	2(15)	1(43)	N(19)	3(24)	2(60)	1(20)
790	N(15)	1(36)	2(15)	3(20)	N(20)	1(37)	2(36)	3(38)
2167	N(26)	3(17)	2(52)	1(21)	N(17)	3(29)	2(15)	1(25)
8269	N(25)	1(23)	2(15)	3(49)	N(15)	1(52)	2(38)	3(38)

Note. The letter "N" indicates that the Lag-0 contingency was not in effect in any of the components of the chain (i.e., that the Lag-4 contingency was in effect in all of them), and the numerals "1," "2," and "3" indicate that the Lag-0 contingency operated in Components 1, 2, and 3, respectively.

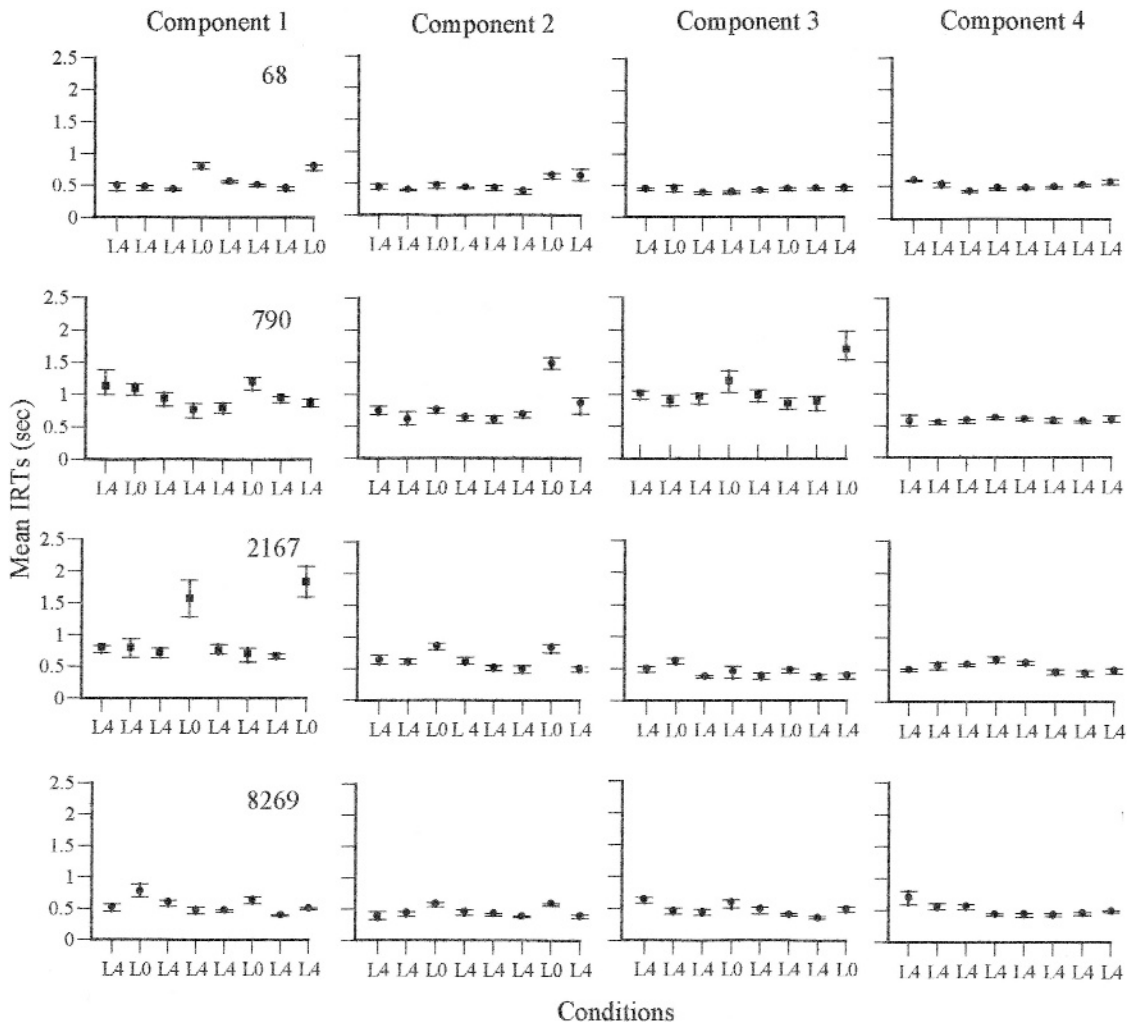


Fig. 4. Mean IRTs in each condition of Experiment 2. The first, second, third, and fourth rows of panels show data for Pigeons 68, 790, 2167, and 8269 in that order. The first column of panels show means of the mean Component-1 IRTs from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. The second, third, and fourth columns show the corresponding means and ranges from Components 2, 3, and 4, respectively. Lag-4 conditions are labeled "L4" and indicate those conditions in which the Lag-4 contingency was in effect during the specific component. Lag-0 conditions are labeled "L0" and indicate those conditions in which the Lag-0 contingency was in effect during the specific component.

1-3 increased by 20% or more in 20 of 24 exposures to the Lag-0 condition (i.e., 4 subjects \times 3 components \times 2 exposures). One exception to the latter finding occurred in Pigeon 790's mean Component-1 IRTs, which decreased slightly in length during the first implementation of the Lag-0 contingency in this component. Likewise, the Lag-0 contingency produced only negligible increases in the length of Pigeon 68's mean Component-3 IRTs, particularly when compared to the large increases in the mean IRTs that some of the other subjects exhibited in this component (see, e.g., the second exposure of Pigeon 790's Component-3 IRTs to the Lag-0 contingency). Despite these exceptions, the results show that the effect of the contingency between Lag-0 IRTs and stimulus change was not limited to the components closest to food. Indeed, the Lag-0 contingency often generated longer IRTs in Component 1 than in Component 2 and longer IRTs in Component 2 than in Component 3 (see, e.g., Subjects 68 and 2167).

Figure 5 shows relative frequency distributions of IRTs in Components 1 (top panel), 2 (middle panel), and 3 (bottom panel) for a representative subject (Subject 790), constructed from the last five sessions of the second exposure to the Lag-0 condition in each of these components and from the immediately preceding Lag-4 conditions. The Lag-0 contingency shifted the mode of the Component-1 IRTs from the second (0.2–0.4) to the fifth (0.8–1.0) bin and flattened the overall distribution. In Components 2 and 3, however, the Lag-0 contingency only produced decreases in the height of the modal (0.2–0.4) IRT bin, with the larger of these decreases occurring in Component 2.

Figure 6 shows the obtained mean durations of Components 1–4 for each subject. The first column of panels shows the means of the mean Component-1 durations from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. The second, third, and fourth columns show the corresponding means and ranges from Components 2–4, respectively. Consistent with the results of Experiment 1, the mean component durations did not vary systematically across conditions, although the mean Component-1 durations tended to be longer than those of the other three components.

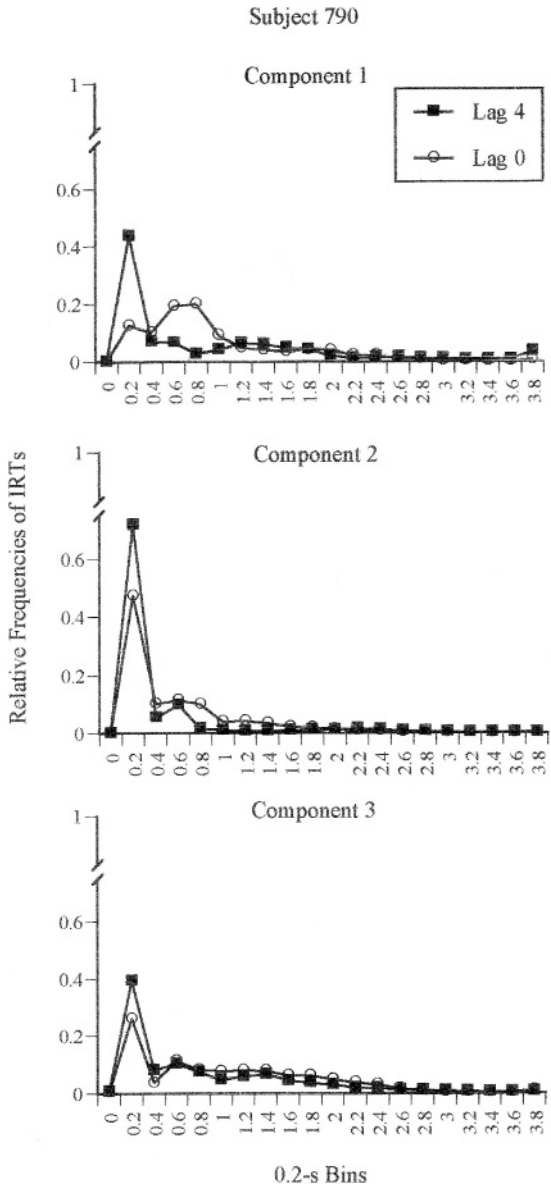


Fig. 5. Relative frequency distributions of IRTs (in 0.2-s bins) from a representative subject, Pigeon 790, during this subject's second exposure to the conditions of Experiment 2. The top panel shows all IRTs in the last five sessions of the condition in which the Lag-0 contingency operated in Component 1 (open circles) and all IRTs from the last five sessions of the preceding condition in which the Lag-4 contingency operated in this component (closed squares). The middle and bottom panels show the corresponding data from Components 2 and 3, respectively. The numbers on the x-axis represent the lower limit of each bin (e.g., 0.3-s IRTs are in the 0.2-s bin). The right-most bin contains IRTs greater than or equal to 3.8 s.

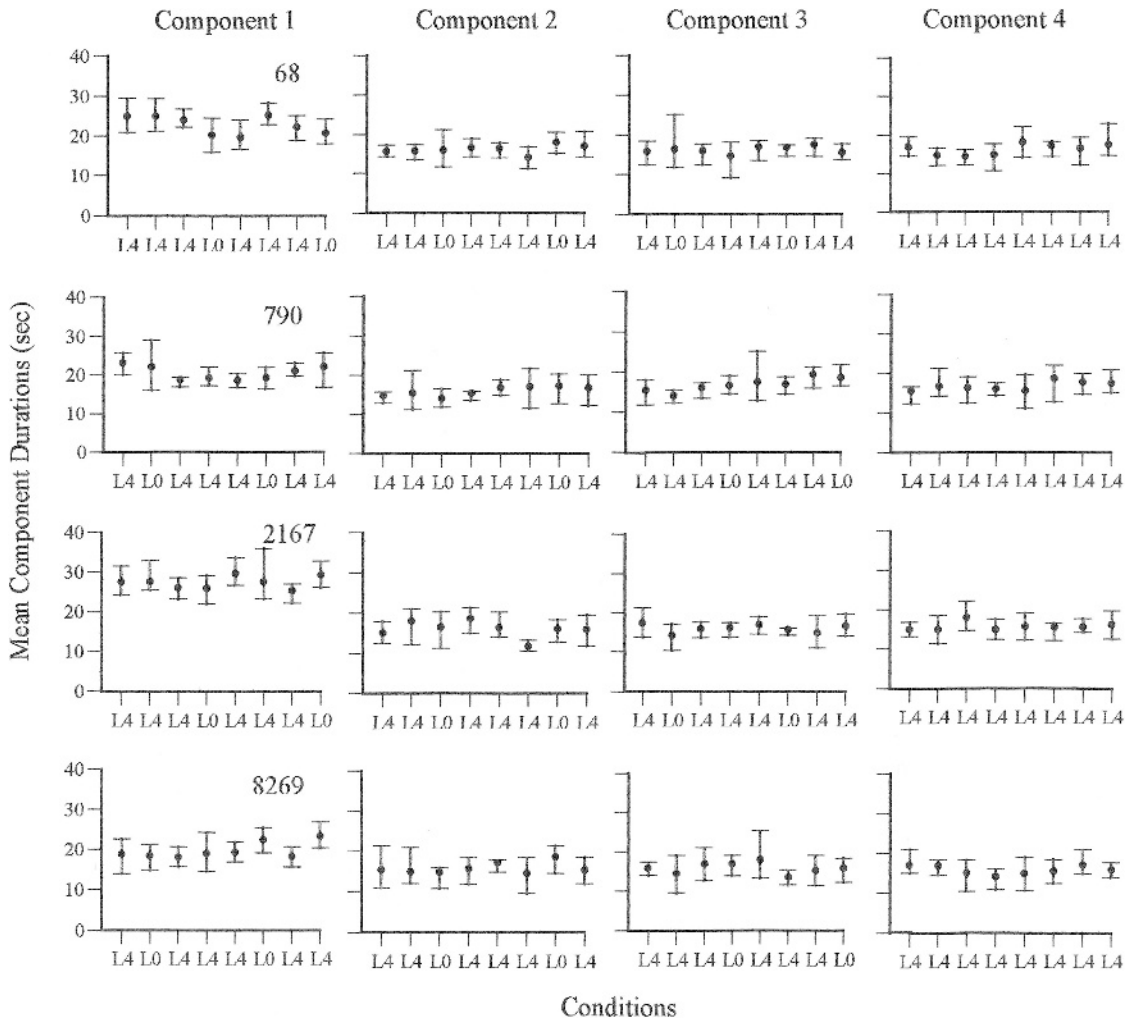


Fig. 6. Mean obtained component durations in each condition of Experiment 2. The first, second, third, and fourth rows of panels show data for Pigeons 68, 790, 2167, and 8269 in that order. The first column of panels shows the means of the mean Component-1 durations from each of the last five sessions of each condition, as well as the ranges of values that composed these grand means. The second, third, and fourth columns show the corresponding means and ranges from Components 2, 3, and 4, respectively. Lag-4 conditions are labeled "L4," and Lag-0 conditions are labeled "L0" as in Figure 4.

In sum, IRTs in Components 1, 2, and 3 usually were longer when component transitions were contingent on Lag-0 IRTs than when they were contingent on Lag-4 IRTs, thus demonstrating that the IRT-lengthening effect of stimulus change is not limited to two-component chained schedules. As in Experiment 1, these findings cannot be attributed to the delays to food signaled by the stimuli correlated with the different components of the chain nor can they be ascribed to a contingency between IRT length in the early components and the time to food, because the

mean IFI was prevented from varying systematically across conditions. Consequently, the results of Experiment 2, like those of Experiment 1, may be attributed to the reinforcing effect of stimulus change.

GENERAL DISCUSSION

The two experiments reported herein investigated the effects of IRT-contingent transitions between the components of chained schedules. Experiment 1 demonstrated that IRTs in the initial component of a two-

component chain were longer when the probability of component transitions varied directly with the most recent IRT than when it varied directly with the fourth IRT in advance of the most recent one. Experiment 2 likewise showed that IRTs in the first, second, and third components of a four-component chain usually were longer when the probability of component transitions was a direct function of Lag-0 IRTs than when it was a direct function of Lag-4 IRTs.

These findings call into question the claim that the concept of conditioned reinforcement is not necessary to explain chained-schedule responding (Baum, 1973; Staddon, 1983). Staddon, for example, argued that "The concept of conditioned reinforcement (that is, the response contingency between pecking and stimulus change) adds nothing to our understanding of chained schedules," and that "Behavior on chained schedules is determined by temporal proximity to food in the same way as behavior on multiple schedules" (p. 466). Because our procedures kept the mean component durations from varying systematically across conditions, however, the present findings cannot be explained in terms of the delays to food signaled by the stimuli correlated with the early components of the chains or in terms of a contingency between IRT length in those components and the delays to food. Consequently, they may be attributed to the reinforcing effect of stimulus change.

This conclusion notwithstanding, it must be pointed out that the results of Experiment 2 are not entirely consistent with the explanation of chained-schedule responding in terms of conditioned positive reinforcement. Specifically, the Lag-0 contingency increased the Component-1 IRTs more than the Component-2 IRTs and the Component-2 IRTs more than the Component-3 IRTs. This finding is at odds with the conditioned-positive-reinforcement account because the conditioned-reinforcement account assumes that the unconditioned reinforcer transfers its reinforcing efficacy to the early stimuli in extended chains via higher-order classical conditioning (e.g., Kelleher & Gollub, 1962). However, higher-order conditioning often produces a weaker effect than does first-order conditioning (Pavlov, 1927). In other words, if higher-order conditioning explains responding on extend-

ed chains, the Lag-0 contingency should have increased Component-3 IRTs more than Component-2 IRTs and Component-2 IRTs more than Component-1 IRTs. Given that the opposite pattern of results occurred, other explanations of chained-schedule responding may need to be considered.

One such explanation is suggested by the results of Dougherty and Lewis (1991). These investigators arranged a discrete-trials procedure in which a key peck in the initial component of a two-component chain canceled the transition to the terminal component and thereby the presentation of food. Despite the negative correlation between pecking in the initial component, on the one hand, and the presentation of the terminal-component stimulus and food, on the other, a high number of key pecks occurred in the initial component, suggesting that the stimulus-stimulus (S-S) contingency between the initial- and terminal-component stimuli competed for control against both of the response-stimulus (R-S) contingencies (i.e., that between responding in the initial component and stimulus change, and that between such responding and the presentation of food).

Perhaps the results of Experiment 2 also are attributable to interactions between S-S and R-S contingencies. Specifically, elicited key pecks may have competed less strongly with the occurrence of long pauses between pecks in the early components than in the later ones. This may explain why the IRT-lengthening effect of stimulus change was larger in Component 1 than in Component 2 and larger in Component 2 than in Component 3.

Other studies (Dinsmoor, Lee, & Brown, 1986; Leung, 1994; Thomas, 1966) suggest that conditioned-negative- (but not conditioned-positive-) reinforcement may explain the direct relation between the reinforcing efficacy of stimulus change and the delays to food that we obtained in Experiment 2. Dinsmoor et al., for example, established key pecking in pigeons by exposing them to four key colors that were followed by food in a recurring sequence. Once key pecking had been established, they scheduled the termination of these colors (or of the first color only) contingent on key pecks, substituting them with another stimulus to avoid darkening the key. Dinsmoor et al. found that rates of

pecking increased in the presence of the first color in the sequence but decreased in the presence of the last color, suggesting that the initial-component stimulus functioned as a conditioned negative reinforcer.

On this view, the longer IRTs in the early components of the four-component chain in Experiment 2 may reflect the occurrence of unmeasured behaviors (e.g., looking away from the response key) that were negatively reinforced by decreased contact with the schedule-correlated stimuli. In other words, the aversiveness of the stimuli in the chain may have varied directly with the delay to the next food delivery. This would result in less off-key behavior in the later components of the chain, which in turn would explain why the Lag-0 contingency had a seemingly weaker effect in these components.

In any case, the present findings demonstrate that the contingency between IRT length and stimulus change can selectively increase IRTs in the early components of chained schedules, just as the contingency between IRT length and food presentation has been shown to do on simple schedules. Future research might be conducted to investigate the behavioral processes (e.g., conditioned positive and/or conditioned negative reinforcement) responsible for the reinforcing effect of stimulus change. Whatever the outcome of such research, the present results clearly establish the concept of conditioned reinforcement as necessary for a complete explanation of the behavior generated and maintained by chained schedules.

REFERENCES

- Baum, W. M. (1973). The correlation based law of effect. *Journal of the Experimental Analysis of Behavior*, 20, 137-153.
- Catania, A. C., Yohalem, R., & Silverman, P. J. (1980). Contingency and stimulus change in chained schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 33, 213-219.
- Dinsmoor, J. A., Lee, D. M., & Brown, M. M. (1986). Escape from serial stimuli leading to food. *Journal of the Experimental Analysis of Behavior*, 46, 259-279.
- Dougherty, D. M., & Lewis, P. (1991). Elicited responding in chain schedules. *Journal of the Experimental Analysis of Behavior*, 36, 475-487.
- Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*. New York: Appleton-Century-Crofts.
- Galbicka, G., & Platt, J. R. (1984). Interresponse-time punishment: A basis for shock-maintained behavior. *Journal of the Experimental Analysis of Behavior*, 41, 291-308.
- Jwaideh, A. R. (1973). Responding under chained and tandem fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 19, 259-267.
- Kelleher, R. T., & Fry, W. T. (1962). Stimulus functions in chained fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 5, 167-173.
- Kelleher, R. T., & Gollub, L. R. (1962). A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 5, 543-597.
- Leung, J. P. (1994). Psychological distance to reward: The aversiveness of the first component stimulus in a chain. *Behavioural Processes*, 32, 67-78.
- Pavlov, I. P. (1927). *Conditioned reflexes: An investigation of the physiological activity of the cerebral cortex* (G. V. Anrep, Ed. & Trans.). London: Oxford University Press.
- Platt, J. R. (1979). Interresponse-time shaping by variable-interval-like interresponse-time reinforcement contingencies. *Journal of the Experimental Analysis of Behavior*, 31, 3-14.
- Renner, K. E. (1964). Delay of reinforcement: A historical review. *Psychological Bulletin*, 61, 341-361.
- Royalty, P., Williams, B. A., & Fantino, E. (1987). Effects of delayed conditioned reinforcement in chained schedules. *Journal of the Experimental Analysis of Behavior*, 47, 41-56.
- Schneider, S. M. (1990). The role of contiguity in free-operant unsignaled delay of positive reinforcement: A brief review. *Psychological Record*, 40, 239-257.
- Staddon, J. E. R. (1983). *Adaptive learning and behavior*. New York: Cambridge University Press.
- Thomas, J. R. (1964). Multiple baseline investigations of stimulus functions in an FR chained schedule. *Journal of the Experimental Analysis of Behavior*, 7, 241-245.
- Thomas, J. R. (1966). Avoidance of a return to the first component of a chain from the terminal component. *Journal of the Experimental Analysis of Behavior*, 9, 435-441.
- Thomas, J. R. (1967). Chained and tandem fixed-interval schedule performance and frequency of primary reinforcement. *Psychological Reports*, 20, 471-480.
- Wallace, F., Osborne, S., & Fantino, E. (1982). Conditioned reinforcement in two-link chain schedules. *Behavior Analysis Letters*, 2, 335-344.
- Weiss, B. (1970). The fine structure of operant behavior during transition states. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules* (pp. 277-311). New York: Appleton-Century-Crofts.
- Williams, B. A., & Royalty, P. (1990). Conditioned reinforcement versus time to reinforcement in chain schedules. *Journal of the Experimental Analysis of Behavior*, 53, 381-393.

Received: November 14, 2003
Final acceptance: May 25, 2007